EMFAC Modeling Change Technical Memo

SUBJECT: INCREASED EVAPORATIVE EMISSIONS DUE TO ETHANOL PERMEATION

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SUMMARY

The emission benefits for Phase 2 RFG were originally correlated to oxygen content and Reid Vapor Pressure (RVP) without regard to the oxygenating species. That is, a gasoline with 5.7% methyl t-butyl ether (MTBE) was assumed to be equivalent with respect to emissions to a gasoline with 10% ethanol (EtOH) because both fuels contained 2% oxygen. Recently completed testing shows that gasoline oxygenated with EtOH results in higher evaporative emissions compared to an MTBE-containing fuel with an equivalent vapor-pressure and oxygen content.

In the study sponsored by the Coordinating Research Council (CRC), the fuel systems of several vehicles were tested for diurnal evaporative permeation emissions with fuels containing either MTBE or EtOH. The results of this study were used as the basis for the proposed changes to the on-road emissions inventory.

The results of the analysis are shown below.

Summary of Increased Evaporative Emissions Due to Ethanol Permeation 2004, Summer Planning Inventory

Emission Source	South Coast Air Basin tons/day	Sacramento AQMD tons/day
Diurnal/Resting Losses	9.2	1.2
Running Losses	4.2	0.7
Hot Soak Losses	4.0	0.5
Total	17.4	2.4

[Note: The final documentation will include an analysis of impacts for the San Francisco Bay Area, San Diego, Sacramento Region, South Coast Air Basin, and the San Joaquin Valley for the years 2002, 2010, 2015, and 2020.]

NEED FOR REVISION

In response to an Executive Order issued by Governor Gray Davis, MTBE was phased out of all gasoline sold in California in 2003. The addition of ethanol to gasoline as a replacement for MTBE was required in 2004. As a result, the fuel correction factors in EMFAC must be updated to reflect the impact that EtOH has on emissions, most notably, higher permeation rates through fuel tank walls, hoses, and fittings.

AFFECTED SOURCE CODE/VERSION

New algorithms to be added.

METHODOLOGY FOR REVISION

The Coordinating Research Council (CRC) sponsored a study (E65) in which the fuel systems of several cars were tested for diurnal evaporative emissions on fuels containing either MTBE or EtOH. Although the test procedure was only designed to estimate the impact of EtOH for the diurnal heating process, staff also developed a methodology to adjust the emission inventory for the running loss and hot soak evaporative emission processes.

The proposed modifications will correct the evaporative emission rates in EMFAC to reflect the presence of EtOH. The development of process specific correction factors is proposed for this purpose. The form of the correction factor is given below.

$$\mathbf{ER_{etoh} = ER_{t,rvp} * (PERMfr * EtRFG2r + 1 - PERMfr)} \qquad \textbf{Eqn 1}$$

Where	$\mathbf{ER_{etoh}}$	is the ethanol fuel emission rate expressed in grams per hour (g/hr)
	$\mathbf{ER_{t,rvp}}$	is the MTBE emission rate expressed in g/hr, corrected for temperature and RVP (internal to EMFAC)
	PERMfr	is the permeation fraction for each evaporative process (equation 3)
	EtRFG2r	is the EtOH to MTBE ratio, as a function of temperature and emission regime (equation 2)

Ethanol-to-MTBE ratio (EtRFG2r)

The CRC E65 permeation study results were modeled as the ratio of diurnal emissions of ethanol-containing fuel to emissions of MTBE-containing fuel. This ratio was found to vary as a function of temperature. For each of the 10 vehicles tested, the 48 hourly diurnal emission rates were fit to the best line (napierian or semi-log) for both EtOH and MTBE-containing fuels. The ratios of EtOH to MTBE permeation rates were calculated for each car, also using a log function (See Figure 1).

The only pattern that could be discerned from the diurnal permeation rate results was that two of the vehicles (5 and 6) had absolute emissions that were five to ten times higher than the others. However, these vehicles had much lower increases in emissions due to EtOH, resulting in lower ratios. A description of the vehicles tested in CRC E65 is presented in Table 1 below.

Table 1 – CRC E65 Test Fleet

Veh #	Vehicle Description	Veh #	Vehicle Description
1	2001 Tacoma Pickup	6	1993 Caprice
2	2000 Odyssey Van	7	1991 Accord
3	1999 Corolla	8	1989 Taurus
4	1997 Caravan Van	9	1985 Sentra
5	1995 Ranger Pickup	10	1978 Cutlass

The increases attributable to EtOH compared to MTBE were derived from the 48-hour diurnal tests of the isolated fuel systems of the 10 vehicles. Staff considered the results for Car 6 anomalous in that the diurnal emissions recorded for the MTBE fuel were higher than for EtOH fuel for the first 24-hour diurnal, but not for the second. For all the other vehicles tested, the EtOH results were consistently higher than the MTBE results (See Figure 2).

In EMFAC, evaporative emissions are modeled utilizing three emission regimes. "**Normal**" emitting vehicles are defined as those that are generally free of defect and have emissions at or below their certification standard. "**Moderate**" emitters have some defect that can be detected through inspection or by the On-Board Diagnostic System (OBD) and emit at levels higher than the certification standard but less than vehicles with liquid leaks. As the name implies, "**Liquid Leakers**" are those vehicles that literally drip fuel. These vehicles are the evaporative equivalent to "Super Emitters" for exhaust.

Given EMFAC's structure, staff decided to group and analyze the CRC data in the following manner:

- 8 normal-emitting cars, 1,2,3,4,7,8,9 & 10,
- 2 moderate-emitting cars 5 and 6.
- The E65 study was designed to have no liquid leakers.

Separate correction factors will be derived for Normal and Moderate emitters, however Liquid Leakers will receive no correction. For vehicle 6, the moderate vehicle with the anomalous MTBE results, the day-2 results for both MTBE and EtOH will also be used for day 1.

The diurnal emissions of the group of vehicles was fit to a semi-logarithmic best line (doubling temperature is a constant temperature difference). These fits are shown in Figure 3 for the Normals and Figure 4 for the Moderates. The resulting ratios are also exponentials. The coefficients of the equations are given in Table 2 below. The ratios are displayed in Figure 5.

EtRFG2r = diurnal rate on EtOH fuel ÷ diurnal rate on MTBE fuel **Eqn 2**

$$= \exp b_1 * \exp (m_1*Temp) / (\exp b_2 * \exp (m_2*Temp))$$

$$= \exp (b_1-b_2) * \exp ((m_1-m_2)*Temp)$$

Where ”b” is the intercept, “m” is the slope of the line, and “Temp” is the ambient temperature.

Table 2
Ethanol Augmentation Ratio Coefficients

Regime	m	b	Regime	m	b
Normal MTBE	0.0698	-9.618	Moderate MTBE	0.0780	-8.4919
Normal EtOH	0.0662	-8.5541	Moderate EtOH	0.0811	-8.6046
Normal Ratio	-0.0036	1.0639	Moderate Ratio	0.0031	-0.1127

Application by Process

Diurnal/Resting Permeation Fraction

The CRC E65 study was only designed to investigate the emission effects of permeation. No liquid leaks were present in the vehicle sample. Vapor losses were excluded from the diurnal results by venting the vapor storage canisters outside of the test enclosure. Therefore, the ethanol increases described above are only applicable to that part of the diurnal emissions attributable to permeation.

To determine this fraction, staff assumed that resting losses were a reasonable approximation for permeation. Resting losses are those evaporative emissions that occur when the engine is not running and the ambient temperature is falling or stable. The ratio of resting loss to the diurnal emissions would approximate the fraction of permeation for the diurnal heating process. This ratio was corrected by a factor of 90% in recognition that not all resting losses would be attributable to permeation.

The ratio was calculated using the relationship between resting loss and diurnal emissions as a function of temperature as estimated by EMFAC. Figure 6 illustrates the diurnal emission rate *vs* temperature, 90% of resting loss *vs* temperature, and their ratio for 79-94 model year fuel injected cars using the 65-110°F correlation.

Running Loss Permeation Fraction

As with diurnal emissions, staff assumed that resting loss was a reasonable surrogate for permeation. Therefore, the ratio of resting losses expressed in grams per hour, to running loss expressed in those units would be used to approximate the permeation fraction for running loss.

EMFAC estimates running loss emissions as a function of ambient temperature at the start of the event and engine running time. To illustrate how EMFAC should handle the impact of EtOH on running losses, the relative running and resting loss emission rates calculated at several starting temperatures was used to derive the permeation fraction. This relationship is shown in Figure 7 for normal fuel-injected, pre-enhanced evap cars that are 9 years old with using 9 RVP gasoline.

Running Loss Temperature

Running losses will be modeled as diurnal emissions taking place at elevated temperatures. Therefore, staff needed to estimate the fuel tank temperature as a function of engine running time. To accomplish this task, staff used instrumented vehicle data where thermocouples were placed at several points of the fuel system. From this data, fuel temperature vs. time histories could be derived over a running loss cycle and during the subsequent hot soak. Data for two ambient temperatures at the start of the test, 75°F and 88°F, were available from the instrumented vehicle data. The generic relationship is shown in Figure 8.

Hot Soak Permeation Fraction

The starting hot soak fuel temperatures were assumed to be fuel temperatures recorded at the end of the running loss test. As with the other evaporative processes, the permeation fraction for hot soak is calculated as the ratio of resting losses in grams per hour to hot soak emissions in those units. EMFAC models hot-soak emissions as a function of ambient temperature and fuel volatility (RVP). The hot soak permeation fractions as a function of temperature are shown in Figure 9 for a normal emitting, 86+ model year fuel-injected vehicle utilizing 9 RVP fuel.

Permeation Fraction

$$\mathbf{PERMfr = 0.9 * ER_{resting} * RVPTCF / (ER_{process} * RVPTCF)} \qquad \textbf{Eqn 3}$$

Where

PERMfr	is the permeation fraction
$ER_{resting}$	is the emission rate for evaporative resting loss in g/h, as a function of temperature, tech group, and emission regime (internal to EMFAC)
RVPTCF	is the vapor pressure and temperature correction factor (internal to EMFAC)
$ER_{process}$	is the emission rate for the particular evaporative process expressed in g/h (internal to EMFAC)
0.9	is the fraction of resting loss assumed to be attributable to permeation

INVENTORY EFFECTS

A summary of the emission inventory estimates is shown in Table 3.

Table 3
Ethanol Permeation Emission Inventory Effects

		SCAB, 2004, Summer Ozone Temperatures		Sacramento County, 2004, Summer Ozone Temperatures	
		Ph 2 Gaso/MTBE	Ph 2 Gaso/EtOH	Ph 2 Gaso/MTBE	Ph 2 Gaso/EtOH
No of Vehicles		9,266,894		862,141	
VMT	veh-mi/d	315,033,000		27,622,000	
No of Trips	no/d	60,941,179		5,736,003	
Diurnal	ton/d	28.2	37.4	3.1	4.3
Diurnal	g/d/unit	2.76	3.67	3.30	4.54
Diurnal Permeation	g/d/unit	1.0	1.9	1.3	2.6
Running Loss	ton/d	79.1	83.3	8.2	8.9
Running Loss	g/mi	0.23	0.24	0.27	0.29
Running Loss Permeation	g/mi	0.01	0.02	0.02	0.05
Hot Soak	ton/d	14.6	18.6	1.6	2.1
Hot Soak	g/trip	0.22	0.28	0.26	0.33
Hot Soak Permeation	g/trip	0.06	0.12	0.08	0.16

Figure 1
EtOH/MTBE ratios from diurnals

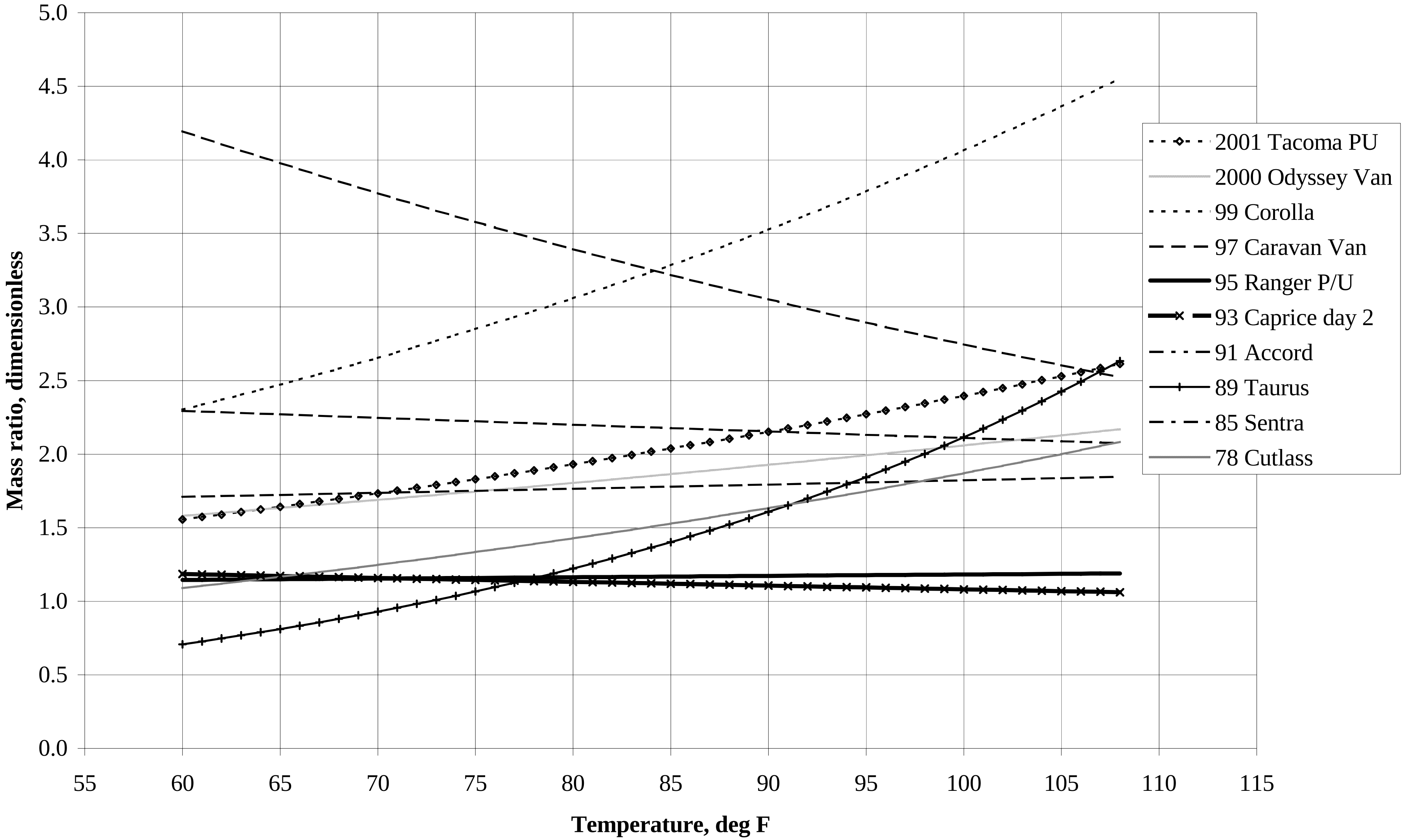
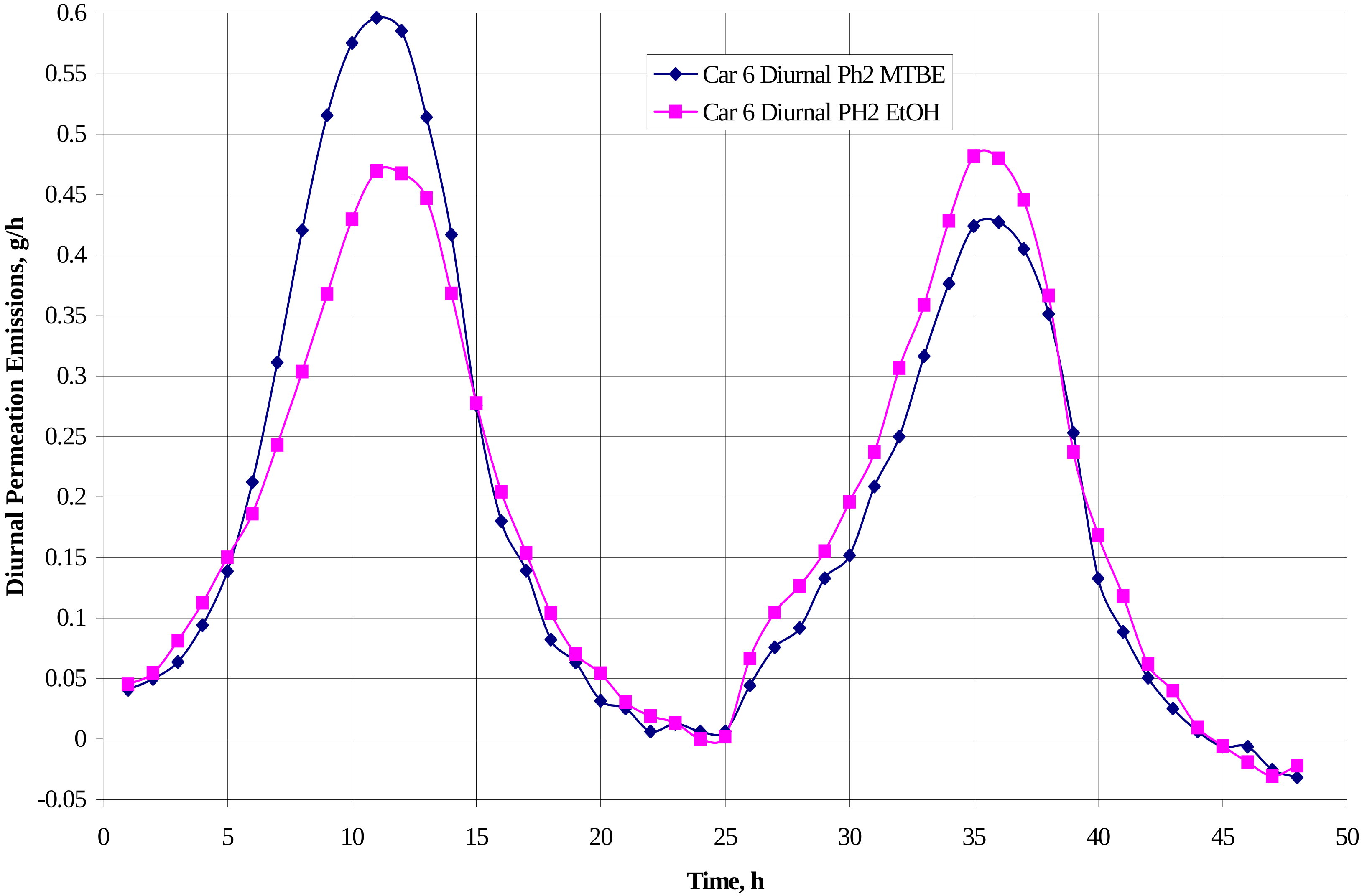


Figure 2
E65 Diurnal Permeation Results, Car 6



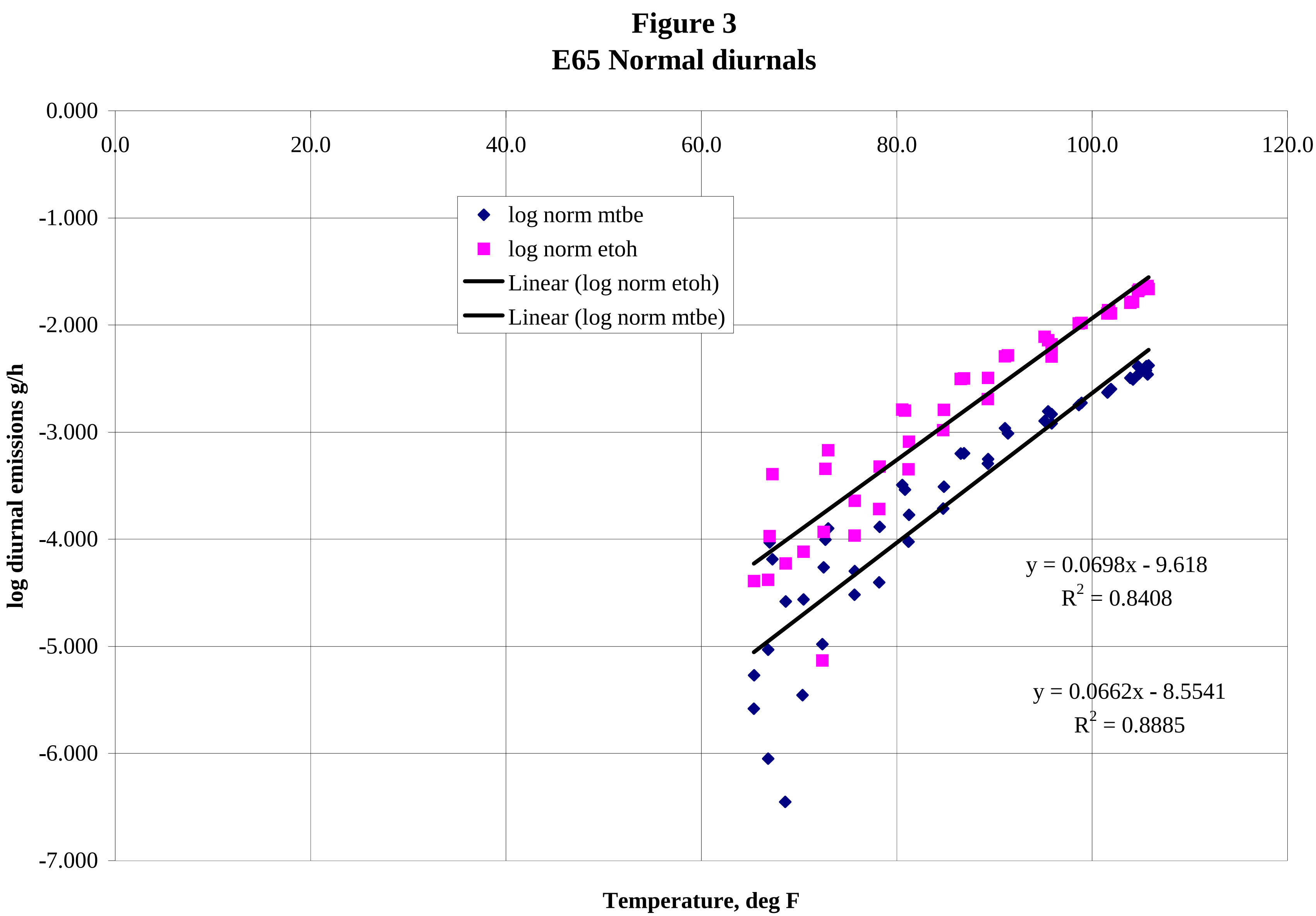


Figure 3
E65 Normal diurnals
0.000
-1.000
-2.000
-3.000
-4.000
-5.000
-6.000
-7.000
0.0
20.0
40.0
60.0
80.0
100.0
120.0
log norm mtbe
log norm etoh
Linear (log norm etoh)
Linear (log norm mtbe)
y = 0.0698x - 9.618
R2 = 0.8408
y = 0.0662x - 8.5541
R2 = 0.8885
log diurnal emissions g/h
Temperature, deg F

Figure 4
E65 Diurnal Moderates (car 6 day 2 repeated)

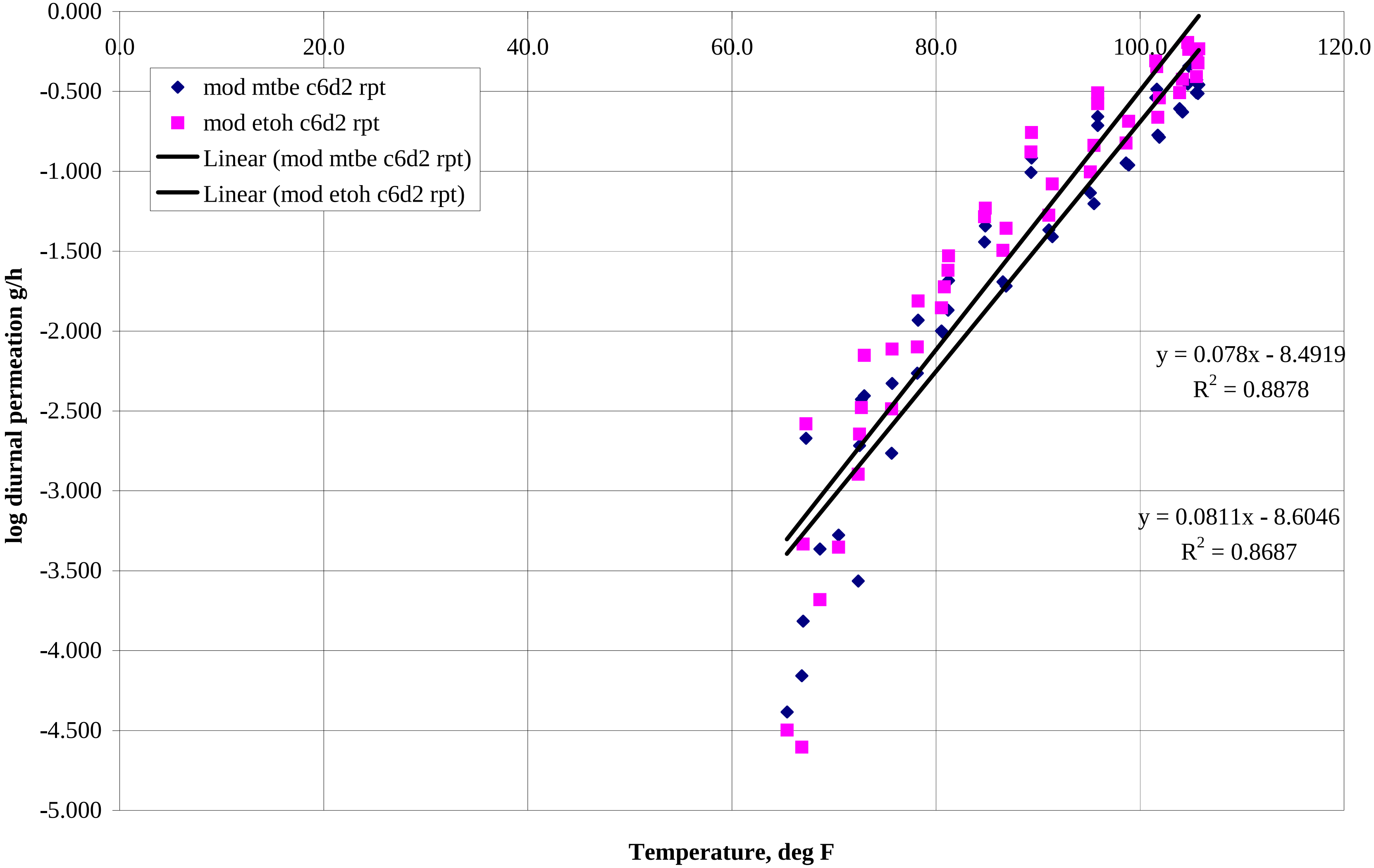


Figure 5
E65 Diurnal Permeation Augmentation Ratios (car 6 day 2 repeated)

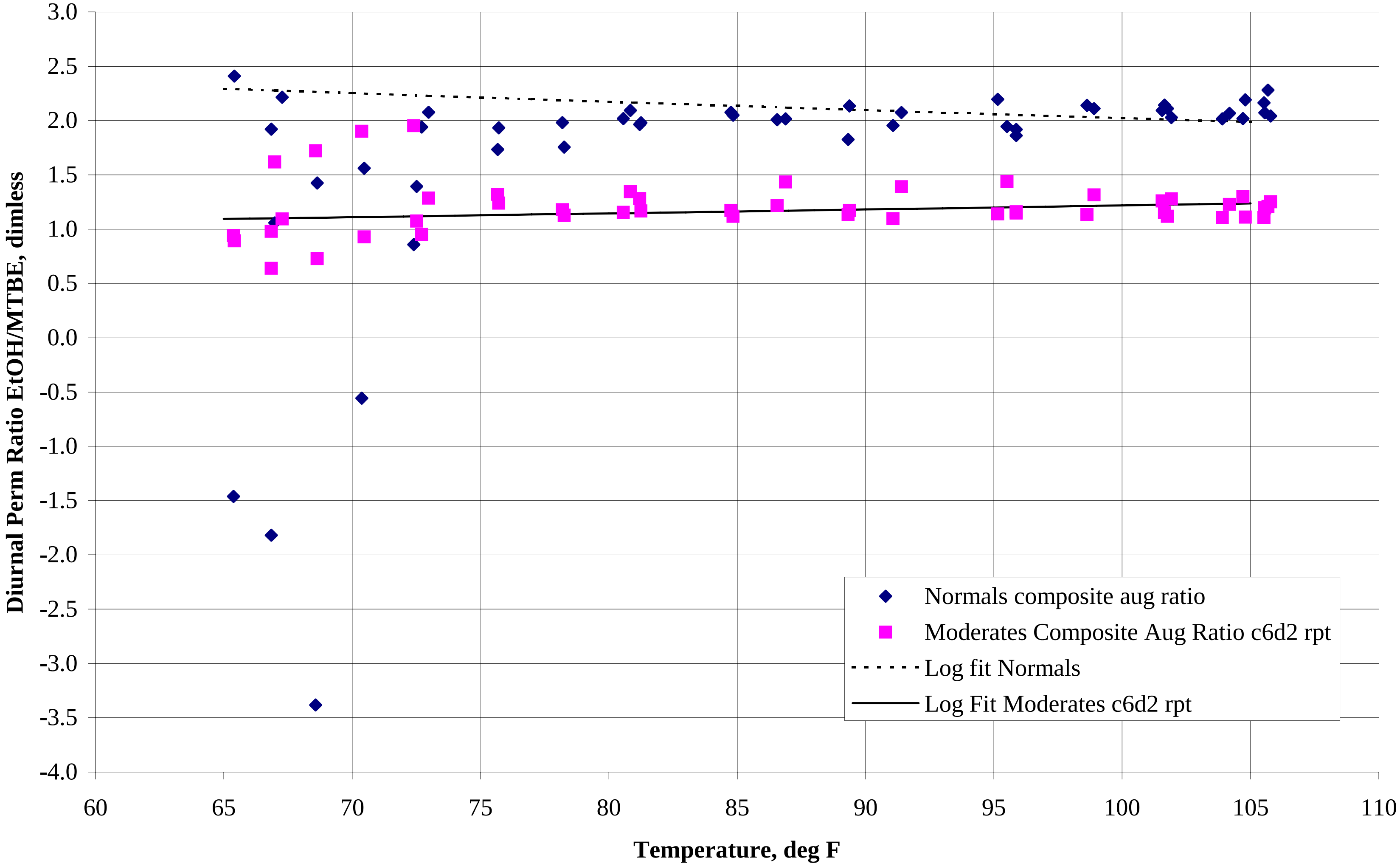


Figure 6
Diurnal Permeation Fraction

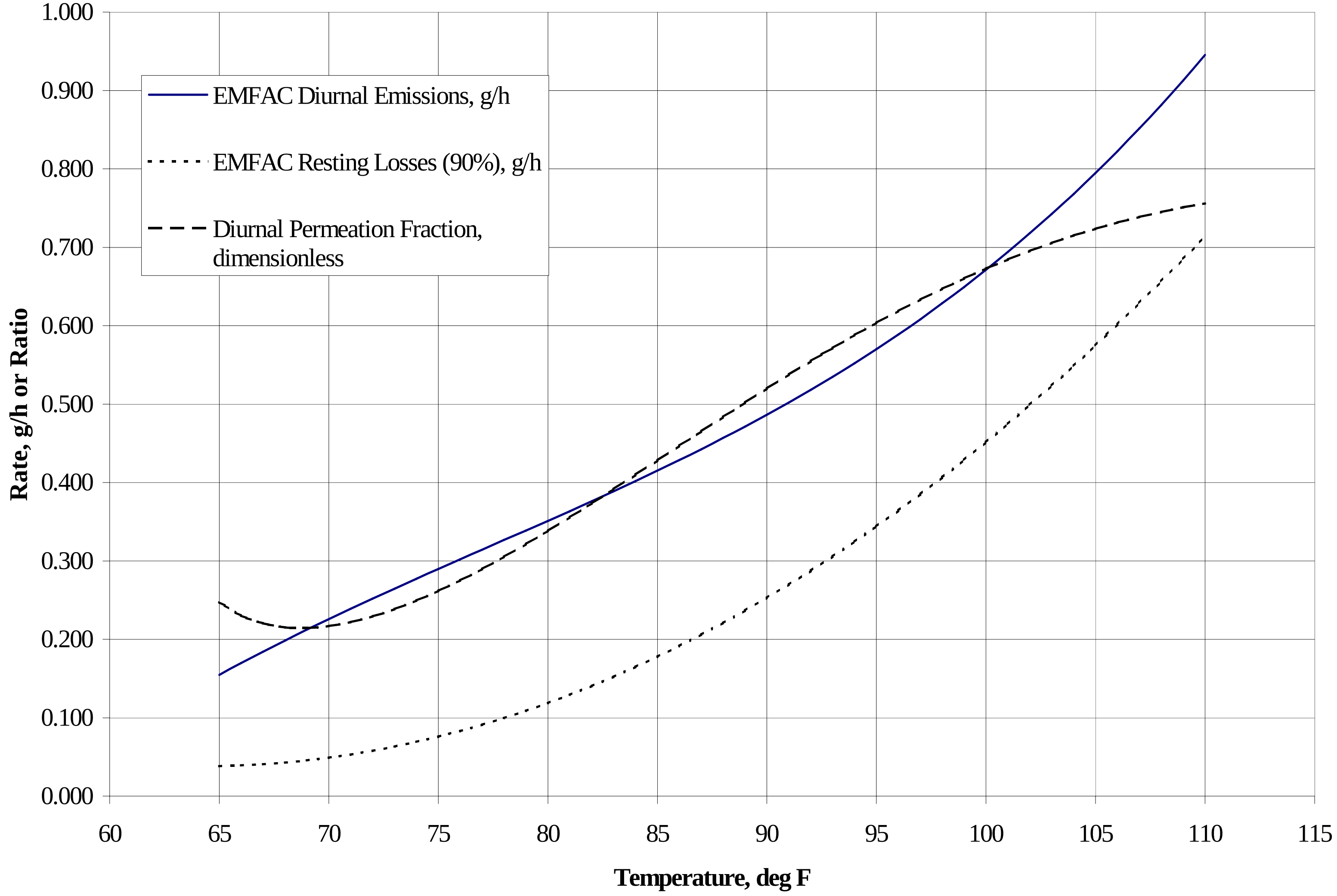
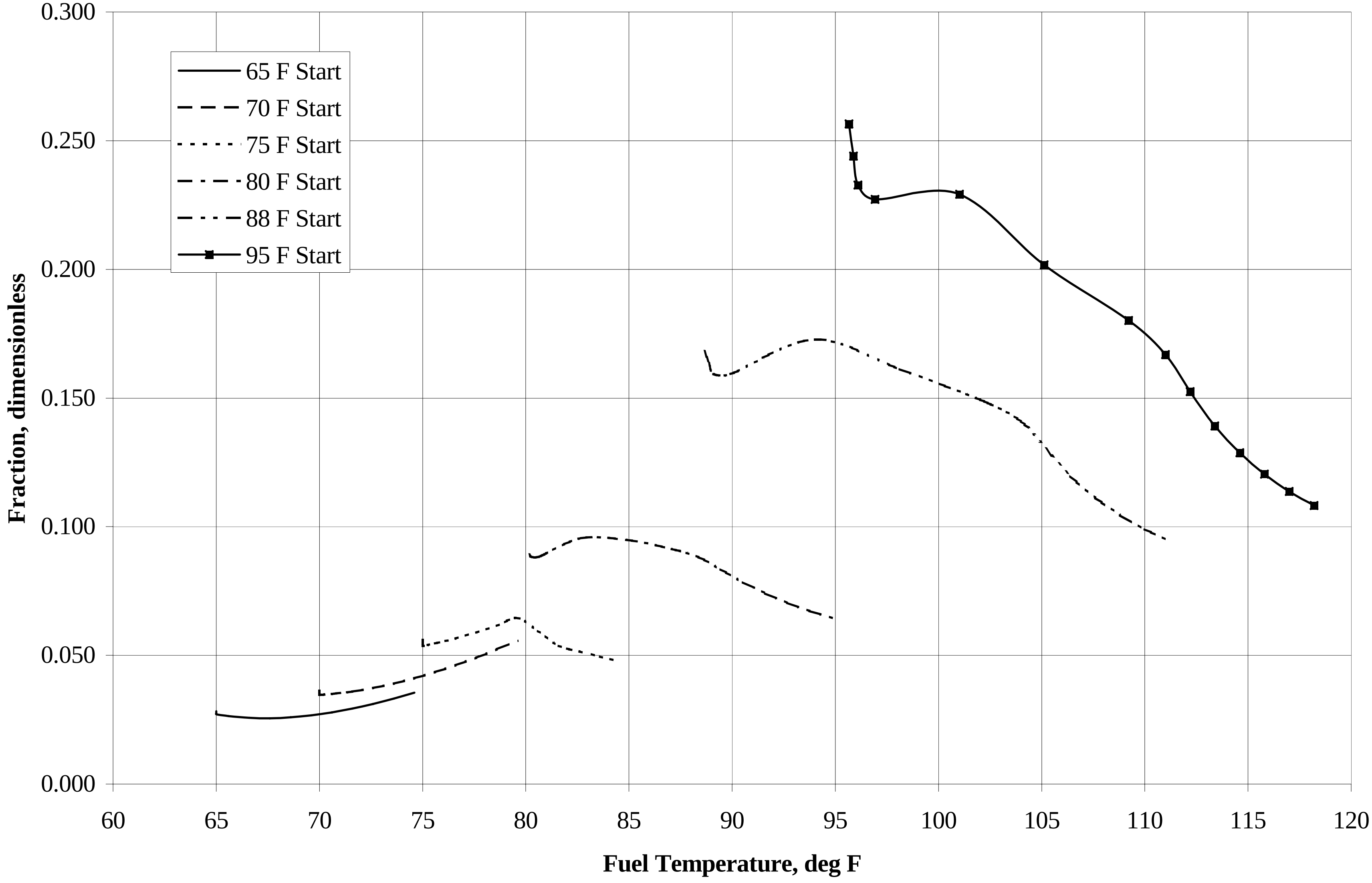


Figure 7
Running Loss Permeation Fraction



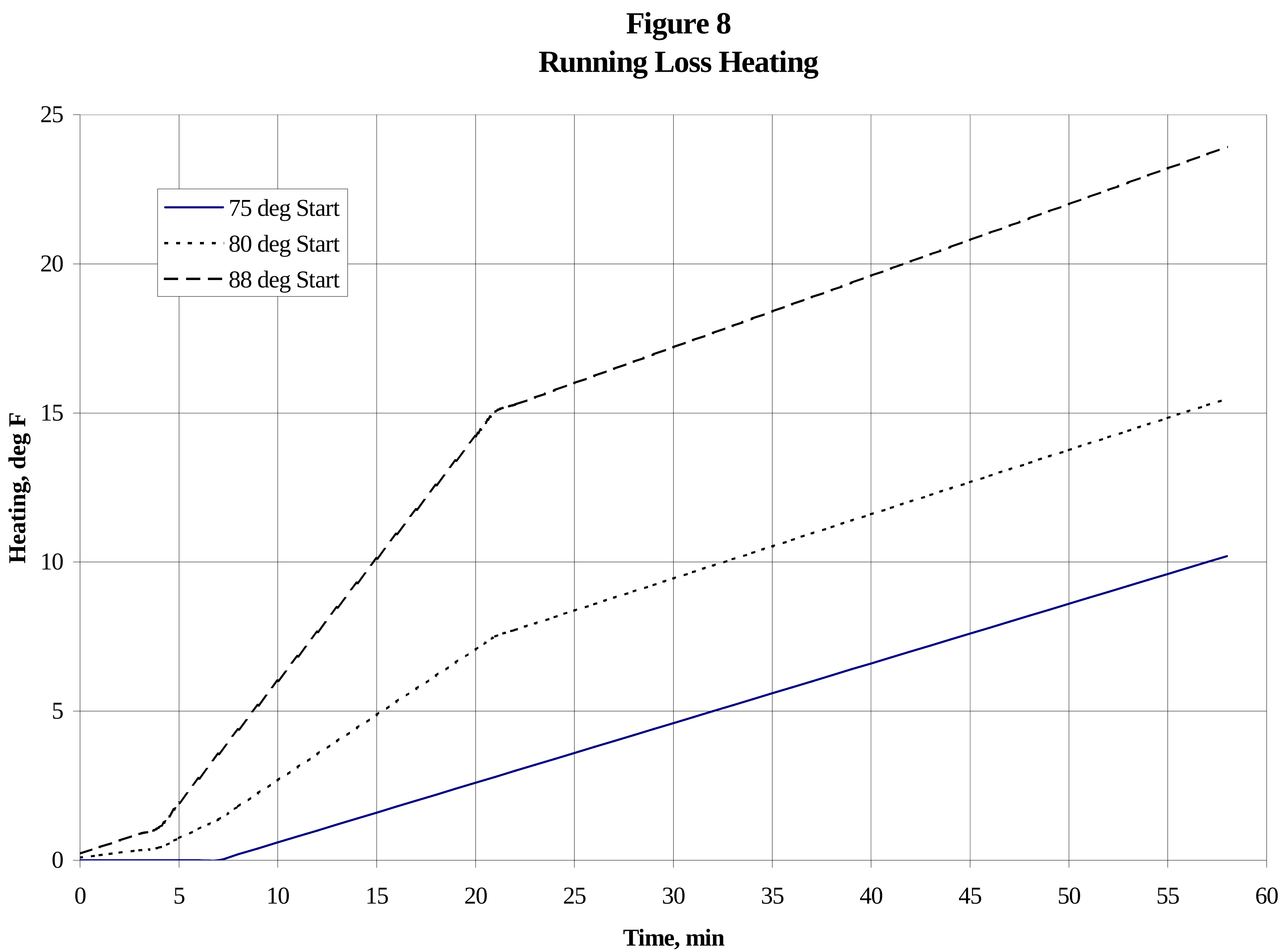


Figure 8
Running Loss Heating
75 deg Start
80 deg Start
88 deg Start
Heating, deg F
Time, min
0
5
10
15
20
25
30
35
40
45
50
55
60

Figure 9
Permeation Fraction, Hot Soak